RICOH

RP401x SERIES

HIGH EFFICIENCY, SMALL PACKAGES, STEP-UP DC/DC CONVERTERS

NO.EA-260-111009

OUTLINE

RP401x Series are high efficiency, step-up DC/DC converter ICs packaged in compact 5pin SOT23-5, or 6pin DFN(PLP)1820-6. This IC can start up from low voltage (Typ.0.6V), therefore, it is suitable for using with single or 2 serial alkaline batteries, or a nickel-metal-hydride (NiMH) battery, or one-cell Lithium-ion (Li+) battery.

This IC consists of an oscillator, a reference voltage unit with soft start, a chip enable circuit, an error amplifier, phase compensation circuits, a slope circuit, a PWM control circuit, a start-up circuit, a PWM/VFM mode control circuit, internal switches and a protection circuit.

A low ripple high efficiency step-up DC/DC converter can be composed of the RP401x with only an inductor, a diode, (resisters for adjustable type), and capacitors. The output voltage of the RP401K001s is adjustable, and others are fixed internally. The output voltage range is from 1.8V to 5.5V. RP401Kxx1A/B series have a MODE pin to alternate between PWM fix and PWM/VFM automatic shift to improve the efficiency at light load. If MODE pin is set "H", the mode is PWM fix, and when the MODE pin is set "L", PWM/VFM automatic shift. The RP401xxx1C and D do not have MODE pin. The RP401xxx1C is PWM/PFM alternative type, and the RP401xxx1D is PWM fixed type.

FEATURES

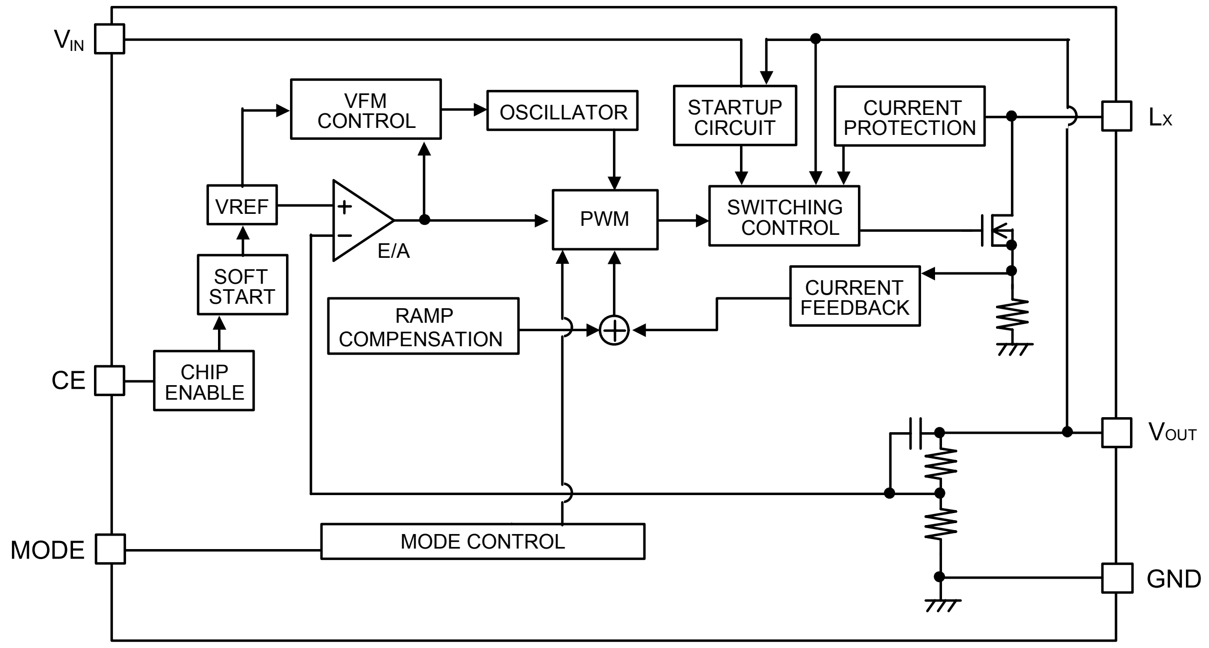
- Low Start-up Voltage guaranteed ··· Typ. 0.6V
- Input Voltage Range ··· 0.6V ~ 5.5V
- High Efficiency ··· 86% (100mA / 3.3V, V_{IN} = 1.5V, 25°C)
- Output current ··· 500mA / 1.8V (V_{IN} = 1.5V) / 5.0V (V_{IN} = 3.3V)
- Built-in Lx switch ··· NMOS: 0.4Ω (V_{OUT} = 3.3V, 25°C)
- PWM Oscillator Frequency ··· 1.2MHz
- Output Voltage Range ··· Fixed type: 1.8V to 5.5V with 0.1V Stepwise
  Adjustable: 1.8V ~ 5.5V
  (Recommendation range of output voltage)
- Lx peak current limit function ··· Typ. 1.0A
- Latch protection delay time ··· 3.3ms (Only applied to A version)
- Small Packages ··· DFN(PLP)1820-6, SOT23-5

APPLICATIONS

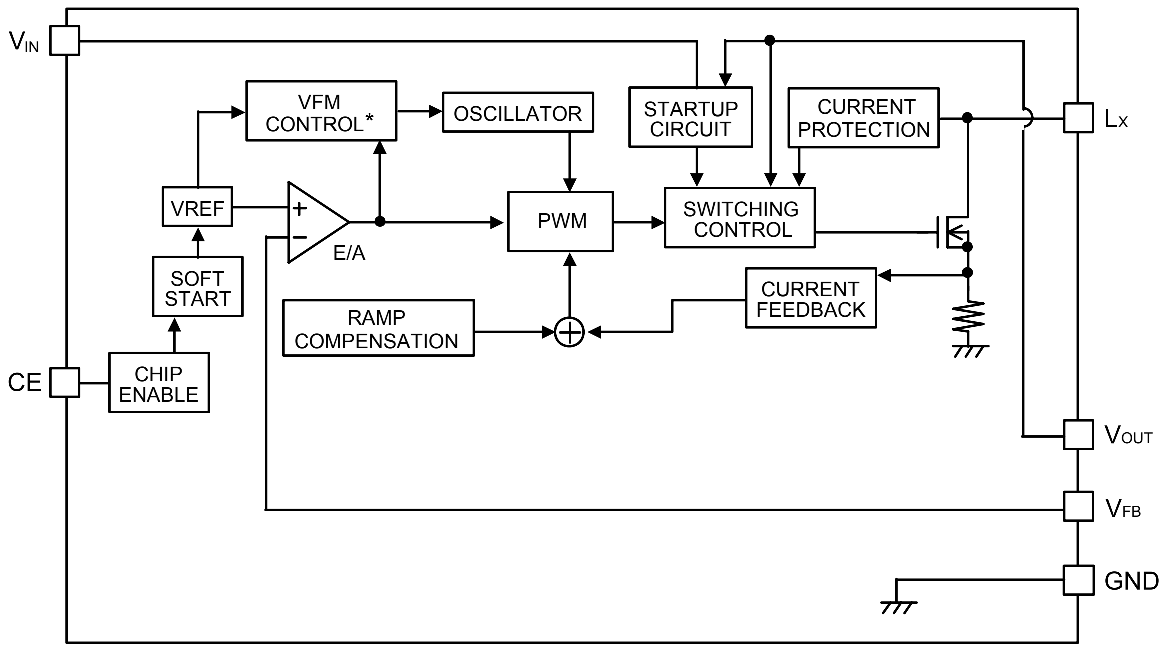
- MP3 players, PDA, cellular phones
- Digital Still Cameras
- LCD Bias Supplies
- Portable blood pressure meter
- Wireless Handset
- GPS

BLOCK DIAGRAMS

Fixed output; RP401Kxx1A/B

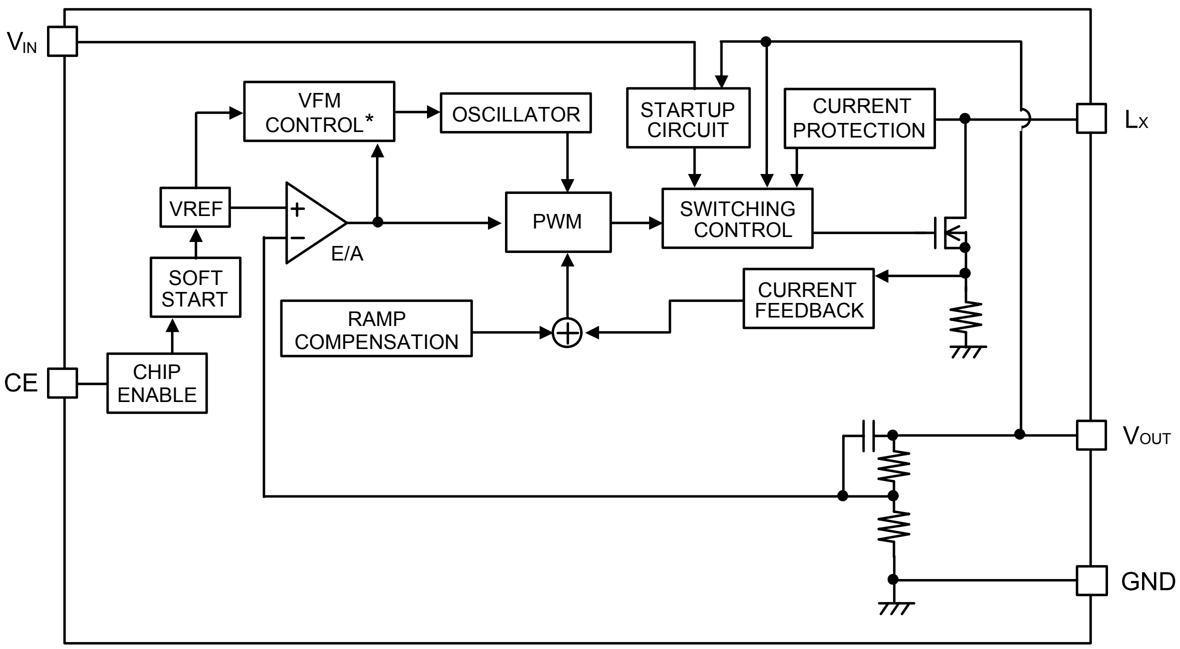


Adjustable output type: RP401K001C/D



*) Applied to PWM/VFM automatic shift, RP401K001C only.

Fixed output type: RP401Nxx1C/D



*) Applied to PWM/VFM automatic shift, RP401Nxx1C only.

SELECTION GUIDE

In the RP400 Series, output Voltage, Type of Output Voltage, and package for the ICs can be selected at the user's request.

Product Name	Package	Quantity per Reel	Pb Free	Halogen Free
RP401Kxx1$-TR	DFN (PLP)1820-6	5,000 pcs	Yes	Yes
RP401Nxx1$-TR-FE	SOT-23-5	3,000 pcs	Yes	Yes

xx: Designation of output voltage
- 00: Adjustable Version (1.8V ~ 5.5V) *** recommendation range of output voltage / DFN(PLP)1820-6 only**
- xx: Fixed version: designation is possible in the range from 1.8V to 5.5V with a step of 0.1V

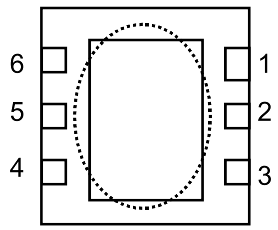
$: Designation of option.
- A: with Mode pin, latch type over-current protection circuit
- B: with Mode pin, without latch type over-current protection circuit
- C: without Mode pin (PWM/VFM automatic shift)
- D: without Mode pin (PWM-fix)

Product code table

Version	MODE pin	Output Voltage	Latch type over-current protection	package
A	Yes	Fixed	Yes	DFN(PLP)1820-6
B	Yes	Fixed	No	DFN(PLP)1820-6
C	No (PWM/VFM automatic shift)	Fixed	No	SOT-23-5
		Adjustable	No	DFN(PLP)1820-6
D	No (PWM fix)	Fixed	No	SOT-23-5
		Adjustable	No	DFN(PLP)1820-6

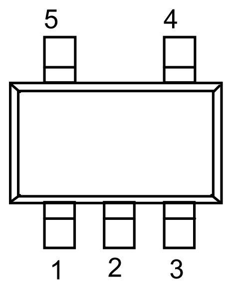
PIN CONFIGURATION

DFN(PLP)1820-6



(Bottom View)

SOT-23-5



(Top View)

PIN DESCRIPTION

RP401Kxx1A/B: DFN(PLP)1820-6

Pin No	Symbol	Pin Description
1	V_{IN}	Power Supply Pin
2	CE	Chip Enable Pin (Active with ”H”)
3	GND	Ground Pin
4	Lx	Internal NMOS Switch Drain Pin
5	MODE	Mode pin for switch over PWM-fix or PWM/VFM alternative
6	V_{OUT}	Output Pin

* Tab is GND level. (They are connected to the reverse side of this IC.) Connected to the GND is the recommendation, leaving it open is also possible.

RP401K001C/D: DFN(PLP)1820-6

Pin No	Symbol	Pin Description
1	V_{IN}	Power Supply Pin
2	CE	Chip Enable Pin (Active with ”H”)
3	GND	Ground Pin
4	Lx	Internal NMOS Switch Drain Pin
5	V_{FB}	Feedback input voltage for setting output voltage
6	V_{OUT}	Output Pin

* Tab is GND level. (They are connected to the reverse side of this IC.) Connected to the GND is the recommendation, leaving it open is also possible.

RP401Nxx1C/D: SOT-23-5

Pin No	Symbol	Pin Description
1	CE	Chip Enable Pin (Active "H")
2	GND	Ground Pin
3	V_{IN}	Power Supply Pin
4	V_{OUT}	Output Pin
5	Lx	Internal NMOS Switch Drain Pin

ABSOLUTE MAXIMAM RATINGS

(GND=0V)

Symbol	Items	Ratings		Unit
V_{IN}	V_{IN} Supply Voltage	-0.3 to 6.0		V
V_{OUT}	V_{OUT} Pin Voltage	-0.3 to 6.0		V
V_{LX}	Lx Pin Input Voltage	-0.3 to 6.0		V
V_{CE}	CE Pin Voltage	-0.3 to 6.0		V
V_{FB}	V_{FB} Pin Voltage	RP401K001C/D	-0.3 to 6.0	V
V_{MODE}	MODE Pin Voltage	RP401K001A/B	-0.3 to 6.0	V
P_D	Power Dissipation *	SOT-23-5	420	mW
		DFN(PLP)1820-6	880	
Ta	Ambient Temp Range	-40 to +85		°C
Tstg	Storage Temp Range	-55 to +125		°C

*) As for Power Dissipation, refer to PACKAGE INFORMATION.

ABSOLUTE MAXIMUM RATINGS
Electronic and mechanical stress momentarily exceeded absolute maximum ratings may cause the permanent damages and may degrade the lifetime and safety for both device and system using the device in the field. The functional operation at or over these absolute maximum ratings is not assured.

RECOMMENDED OPERATING CONDITIONS (ELECTRICAL CHARACTERISTICS)
All of electronic equipment should be designed that the mounted semiconductor devices operate within the recommended operating conditions. The semiconductor devices cannot operate normally over the recommended operating conditions, even if when they are used over such conditions by momentary electronic noise or surge. And the semiconductor devices may receive serious damage when they continue to operate over the recommended operating conditions.

ELECTRICAL CHARACTERISTICS

Adjustable types (RP401K001C/D) (Ta=25°C)

Symbol	Item	Conditions		MIN.	TYP.	MAX.	Unit
V_{IN}	Input Voltage					5.5	V
Vstart	Start-up Voltage	Load current =1mA			0.6	0.8	V
Vhold	Hold-on Voltage	Load current=1mA		0.6			V
I_{DD1}	Quiescent Current 1	V_{IN}=2V, V_{OUT}=2.5V, V_{FB}=0V			380	500	μA
I_{DD2}	Quiescent Current 2 (No switching)	001C	V_{IN}=V_{OUT}=5.5V, V_{FB}=1.0V		130	190	μA
		001D			230	320	μA
Istandby	Standby Current	V_{IN}=V_{OUT}=5.5V, V_{CE}=0V			0.15	3.00	μA
V_{FB}	Feedback Voltage	V_{IN}=V_{OUT}=3.3V		0.588	0.600	0.612	V
ΔV_{OUT} /ΔTa	Output-Voltage Temperature Coefficient	-40°C≤Ta≤85°C			±80		ppm /°C
Fosc	Switching Frequency	V_{IN}=V_{OUT}=3.3V, V_{FB}=0V		1020	1200	1380	kHz
Δfosc /ΔTa	Switching Frequency Temperature Coefficient	-40°C≤Ta≤85°C			±0.2		kHz /°C
R_{ONN}	NMOS On-Resistance (*1)	V_{OUT}=3.3V			0.4		Ω
I_{CEH}	CE "H" Input Current	V_{IN}=V_{OUT}=V_{CE}=5.5V				0.2	μA
I_{CEL}	CE "L" Input Current	V_{IN}=V_{OUT}=5.5V, V_{CE}=0V		-0.2			μA
I_{FBH}	FB "H" Input Current	V_{IN}=V_{OUT}=V_{FB}=5.5V				0.2	μA
I_{FBL}	FB "L" Input Current	V_{IN}=V_{OUT}=5.5V, V_{FB}=0V		-0.2			μA
I_{LX}	Lx Leakage Current	V_{IN}=V_{OUT}=V_{LX}=5.5V, V_{CE}=0V				2	μA
I_{Lxpeak}	Lx Current limit (*2)	V_{IN}=V_{SET}x0.5V		0.86	1.00		A
V_{CEH}	CE Input Voltage "H"			0.7			V
V_{CEL}	CE Input Voltage "L"					0.4	V
Maxduty	Maximum Duty Cycle	V_{IN}=V_{OUT}=3.3V, V_{FB}=0V		80	88	95	%
tstart	Soft start Time	V_{IN}=1.65V, V_{OUT}=3.3V, the time interval from V_{CE} changing from 0V to 1.5V edge to V_{OUT} being 2.97V			0.7	3.0	ms

*1) Guaranteed by design. NMOS On-Resistance depends on the V_{OUT} voltage.
*2) Lx limit current changes according to the switching duty ratio.

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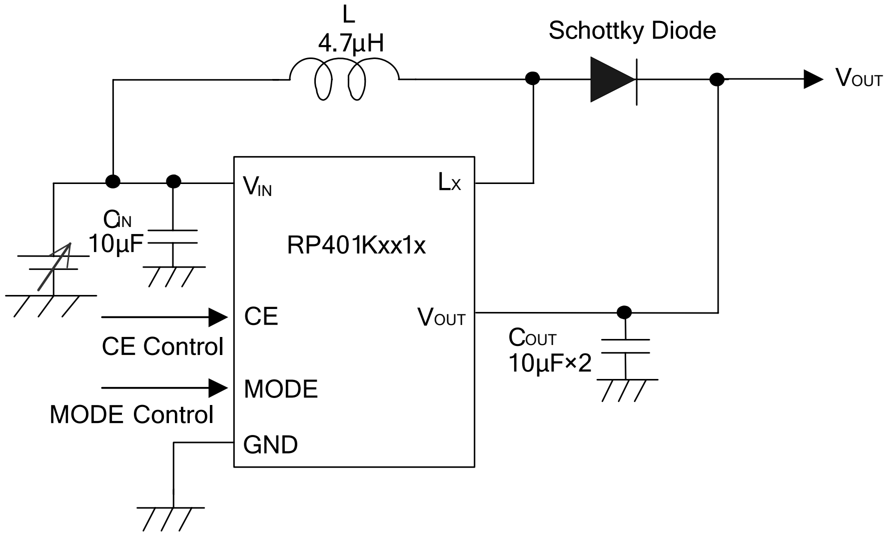
Fixed output voltage types (RP401Kxx1A/B, RP401Nxx1C/D) (Ta=25°C)

Symbol	Item	Conditions		MIN.	TYP.	MAX.	Unit
V_{IN}	Input Voltage					5.5	V
Vstart	Start-up Voltage	Load current =1mA			0.6	0.8	V
Vhold	Hold-on Voltage	Load current=1mA		0.6			V
I_{DD1}	Quiescent Current 1	V_{IN}=0.5xV_{SET}, V_{OUT}=0.95xV_{SET}			V_{OUT}x90 +130	V_{OUT}x100 +250	μA
I_{DD2}	Quiescent Current 2 (No switching)	xx1A/B/C	V_{IN}=V_{OUT}=5.5V		130	190	μA
		xx1D			230	320	μA
Istandby	Standby Current	V_{IN}=V_{OUT}=5.5V, V_{CE}=0V			0.15	3.00	μA
V_{OUT}	Output Voltage	V_{IN}=V_{CE}=1.5V		x0.98		x1.02	V
ΔV_{OUT} /ΔTa	Output-Voltage Temperature Coefficient	-40°C≤Ta≤85°C			±80		ppm /°C
Fosc	Switching Frequency	V_{IN}=V_{OUT}=3.3V, V_{FB}=0V		1020	1200	1380	kHz
Δfosc /ΔTa	Switching Frequency Temperature Coefficient	-40°C≤Ta≤85°C			±0.2		kHz /°C
R_{ONN}	NMOS On-Resistance (*1)	V_{OUT}=3.3V			0.4		Ω
I_{CEH}	CE "H" Input Current	V_{IN}=V_{OUT}=V_{CE}=5.5V				0.2	μA
I_{CEL}	CE "L" Input Current	V_{IN}=V_{OUT}=5.5V, V_{CE}=0V		-0.2			μA
I_{MODEH}	MODE "H" Input Current	V_{IN}=V_{OUT}=V_{MODE}=5.5V				0.2	μA
I_{MODEL}	MODE "L" Input Current	V_{IN}=V_{OUT}=5.5V, V_{MODE}=0V		-0.2			μA
I_{LX}	Lx Leakage Current	V_{IN}=V_{OUT}=V_{LX}=5.5V, V_{CE}=0V				2	μA
I_{Lxpeak}	Lx Current limit (*2)	V_{IN}=V_{SET}x0.5V		0.86	1.00		A
V_{CEH}	CE Input Voltage "H"			0.7			V
V_{CEL}	CE Input Voltage "L"					0.4	V
Maxduty	Maximum Duty Cycle	V_{IN}=V_{OUT}=0.95 x V_{SET}		80	88	95	%
tstart	Soft start Time	V_{IN}=V_{SET} x 0.5, the time interval from V_{CE} changing from 0V to 1.5V edge to V_{OUT} being V_{SET} x 0.9			0.7	3.0	ms
tprot	Protection Delay Time	V_{IN}=V_{CE}=3.3V			3.3	5.0	ms

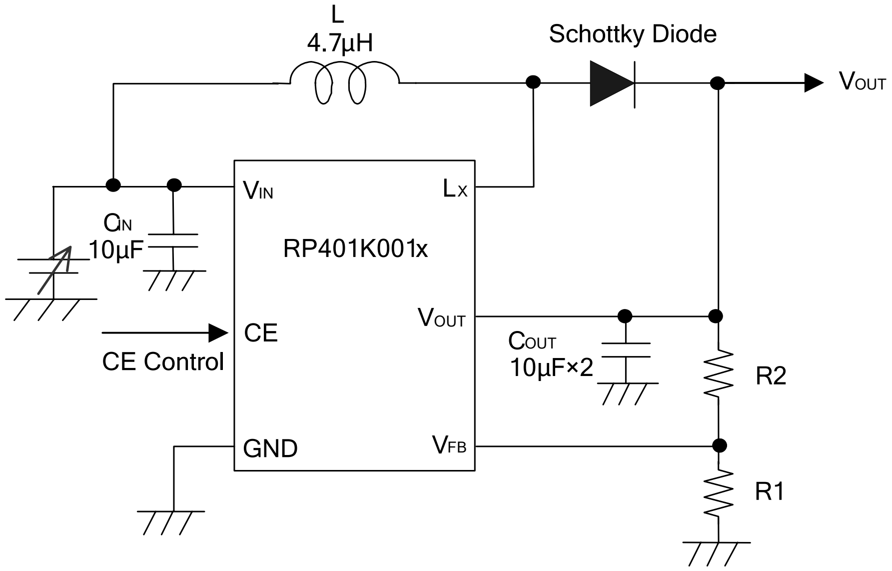
*1) Guaranteed by design. NMOS On-Resistance depends on the V_{OUT} voltage.
*2) Lx limit current changes according to the switching duty ratio.
*3) Applied to A/B version
*4) Applied to A version.

APPLICATION NOTES

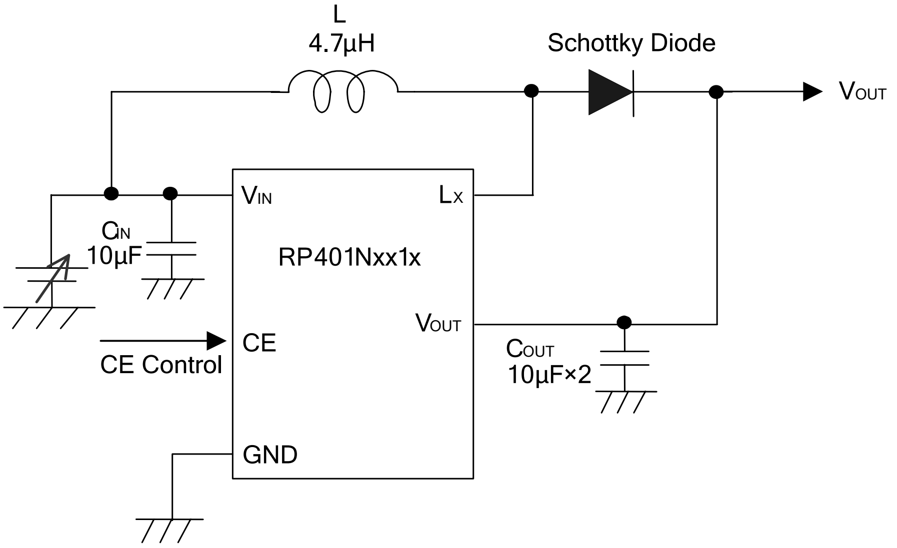
Fixed Output Voltage Type (RP401Kxx1A/B)



Adjustable output type (RP401K001C/D)



Fixed output type (RP401Nxx1C/D)



External components

Capacitor C_{IN}: C1608JB0J106M (TDK), C_{OUT}:

V_{OUT}[V]	ILmax<700mA	ILmax≥700mA
1.8≤V_{OUT}<3.3	C1608JB0J106M×2 (10μF×2,TDK)	
3.3≤V_{OUT}≤5.5	C1608JB0J106M (10μF,TDK)	C1608JB0J106M×2 (10μF×2,TDK)

Diode: ILmax<700mA, CRS02 (TOSHIBA). ILmax≥700mA, CMS06(TOSHIBA)
Inductor: SLF7028T-4R7M1R5-PF (TDK), depending on the conditions, smaller L can be used with.
(ex. VLS2012: TDK)

● Setting of Output Voltage for RP401K001C/D

Output voltage can be set with divider resistors for voltage setting, R1 and R2 as shown in the typical application. Refer to the next formula.

Output Voltage = $V_{FB} \times (R1 + R2) / R1$ (V_{FB} = 0.6V)
Recommended value of resistors: Choose R1 and R2 so as to become (R1 + R2) being lower than 100kΩ.

Make sufficient power supply and ground. The large switching current may flow through the power line and GND line. If their impedance is high, the internal voltage of the IC may shift by the switching current and unstable operation may result. At turning off the built-in Lx switch, an over-shoot spike on the output may be generated by the inductor, therefore voltage rating of the output capacitor and the diode is 1.5 or more times as much as setting output voltage.

Use a diode of a low Vf Schottky type with high switching speed, low reverse current, and the current rating.

The RP401x uses the V_{OUT} voltage as the main power supply after start-up. Therefore the capacitor between Vout and GND has a role of the bypass capacitor for this IC. Use capacitors with a capacity of 10μF or more for

V_{OUT} pin. Consider the bias shift, choose the enough capacity of the capacitor. A ceramic capacitor (10μF) between V_{IN} and ground should be set.

The inductor value recommendation is 4.7μH. Choose an inductor that has small D.C. resistance and large enough permissible current and hard to reach magnetic saturation.

If the spike noise on Lx pin is large, put a snub circuit (CR serial connection etc.) in parallel with the diode and reduce the spike noise. The time constants of CR depends on the PCB and have an impact on the efficiency, therefore fully evaluation is necessary. (Basic value is 10ohm and 300pF)

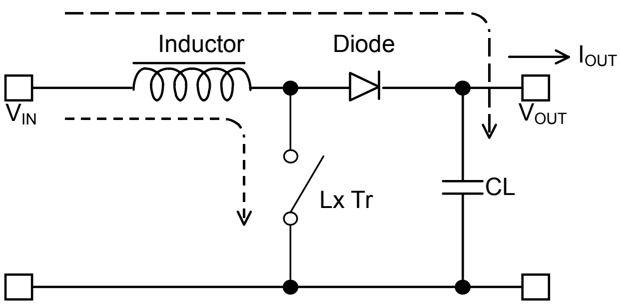
The MODE pin is controlled with a logic voltage. To make it "H", 1.0V or more must be forced to the MODE pin. If power supply is less than 1.0V, MODE pin must be pulled up to V_{OUT}.

The RP401xxxxA can reset the latch protection with CE signal. If C_{IN} is too large, and V_{IN} does not reach 0.8V, even if the IC starts up with CE signal, the latch operation may not be reset correctly. The sequence of V_{IN} and CE must be cared. In the case of CE pin pulled-up to V_{IN} pin or V_{OUT} pin, the operation of latch protection reset may not work correctly.

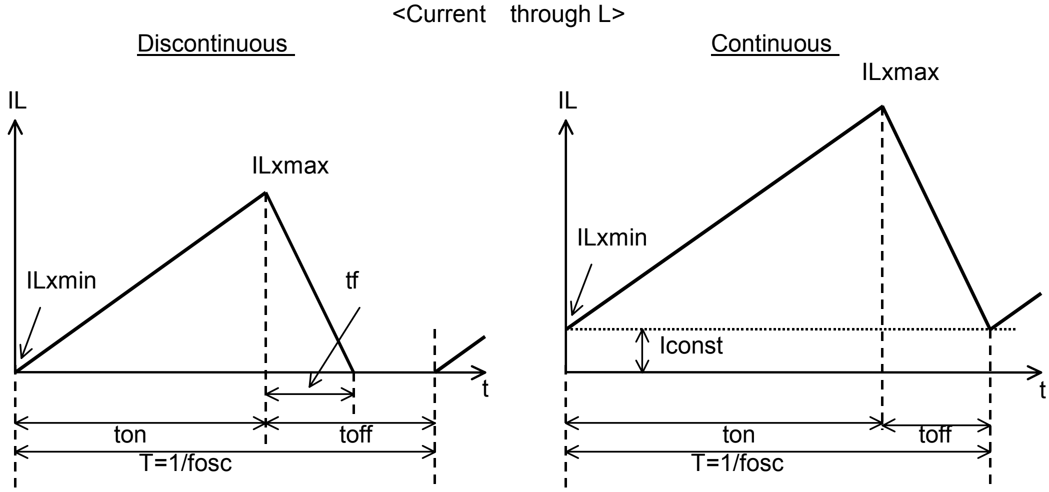
*****The performance of power circuit using those Ics extremely depends upon the peripheral circuits. Pay attention in the selection of the peripheral circuits. In particular, design the peripheral circuits in a way that the values such as voltage, current, and power of each component, PCB patterns and the IC do not exceed their respected rated values. (such as the voltage, current , and power)

OUTPUT CURRENT OF STEP-UP CIRCUIT AND EXTERNAL COMPONENTS

<Basic Circuit>



<Current through L>



There are two modes, or discontinuous mode and continuous mode for the PWM step-up switching regulator depending on the continuous characteristic of inductor current. During on time of the transistor, when the voltage added on to the inductor is described as V_{IN}, the current is $V_{IN} \times t / L$.

Therefore, the electric power, P_{ON}, which is supplied with input side, can be described as in the next formula.

$$P_{ON} = \int_0^{ton} V_{IN}^2 \times t/L \, dt \quad \cdots\cdots \text{Formula 1}$$

With the step-up circuit, electric power is supplied from power source also during off time. In this case, input current is described as $(V_{OUT} - V_{IN}) \times t / L$, therefore electric power, P_{OFF} is described as in the next formula.

$$P_{OFF} = \int_0^{tf} V_{IN} \times (V_{OUT} - V_{IN}) t/L \, dt \quad \cdots\cdots \text{Formula 2}$$

In this formula, tf means the time of which the energy saved in the inductance is being emitted. Thus average electric power, P_{AV} is described as in the next formula.

$$P_{AV} = 1/(ton + toff) \times \{\int_0^{ton} V_{IN}^2 \times t/L \, dt + \int_0^{tf} V_{IN} \times (V_{OUT} - V_{IN}) t/L \, dt\} \quad \cdots\cdots \text{Formula 3}$$

In PWM control, when tf = toff is true, the inductor current becomes continuous, then the operation of switching regulator becomes continuous mode. In the continuous mode, the deviation of the current is equal between on time and off time.

$V_{IN} \times ton / L = (V_{OUT} - V_{IN}) \times toff / L$ ··················· Formula 4

Further, the electric power, PAV is equal to the output electric power, $V_{OUT} \times I_{OUT}$, thus,

$I_{OUT} = fosc \times V_{IN}^2 \times ton^2 / \{2 \times L (V_{OUT} - V_{IN})\} = V_{IN}^2 \times ton / (2 \times L \times V_{OUT})$ ··················· Formula 5

When I_{OUT} becomes more than $V_{IN} \times ton \times toff / (2 \times L \times (ton + toff))$, the current flows through the inductor and the mode becomes continuous. The continuous current through the inductor is described as Iconst, then,

$I_{OUT} = fosc \times V_{IN}^2 \times ton^2 / (2 \times L \times (V_{OUT} - V_{IN})) + V_{IN} \times Iconst / V_{OUT}$ ··················· Formula 6

In this moment, the peak current, Ilxmax flowing through the inductor and the driver Tr. Is described as follows:

$Ilxmax = Iconst + V_{IN} \times ton / L$ ··················· Formula 7

With the formula 4, 6 and Ilxmax is

$Ilxmax = V_{OUT} / V_{IN} \times I_{OUT} + V_{IN} \times ton / (2 \times L)$ ··················· Formula 8

However, $ton = (1 - V_{IN} / V_{OUT}) / fosc$

Therefore, peak current is more than I_{OUT}. Considering the value of Ilxmax, the condition of input and output, and external components should be selected.

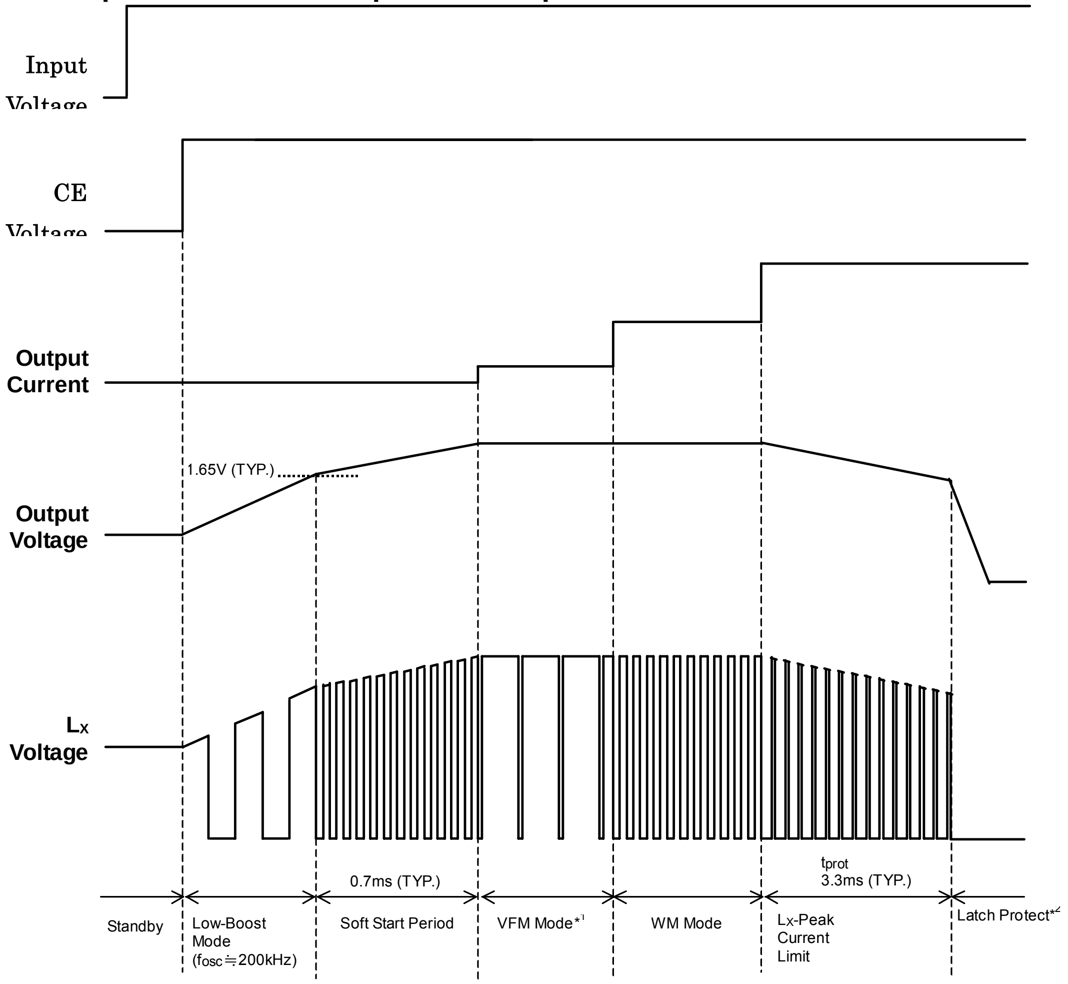
In the formula 7, peak current Ilxmax at discontinuous mode can be calculated. Put Iconst = 0 in the formula.

The explanation above is based on the ideal calculation, and the loss caused by Lx switch and external components is not included.

Select the inductor and the diode with considering the peak current of the (Formula 8).

■ TIMING CHART

Soft start operation and Latch protection operation



*1) Applied to A/B/C version. (MODE="L" for version A/B)

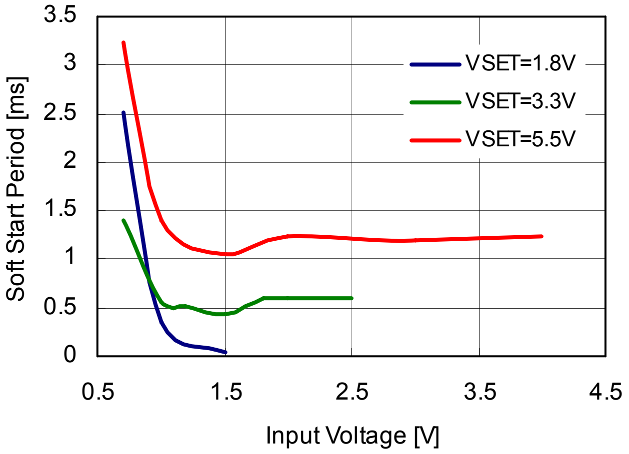
*2) Applied to A version only.

<Start-up> When the CE pin becomes from "L" to "H", then the DC/DC converter starts up. In the RP401 series, low input voltage (Typ. 0.6V) operation is possible due to the low- boost mode. Until the output voltage reaches 1.65V (Typ.) the mode is low-boost mode. When the output voltage becomes 1.65V or more, to suppress the inrush current, soft start operation starts and boosts the output voltage to set value.

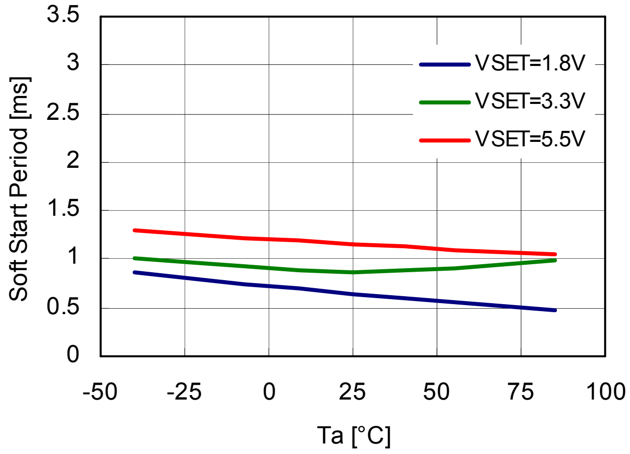
*) At the low-boost mode, the oscillator frequency is reduced to 200kHz (Typ.), therefore, compared with the normal operation frequency 1.2MHz, the boost capability is worse. Therefore, step-up ratio and load current must be cared.

*) Soft-start time depends on the set output voltage, input voltage, temperature, and the load current. Refer to the next graphs.

Soft Start Period vs. Input Voltage RP401xxx1x
I_{OUT}=1mA



Soft Start Period vs. Temperature RP401xxx1x
$V_{IN}=V_{SET}\times0.5$, RL=1kΩ



<Over-current protection operation>

If the Lx peak current reaches 1.0A (Typ.), then Lx peak current limit circuit operates and control the duty ratio of Lx switch.

<Latch Protection Operation> applied to A version only

If over current state continues for a protection delay time (t_{PROT}), then latch protection function starts and latch the internal driver switch being off and the operation of DC/DC converter will stop.

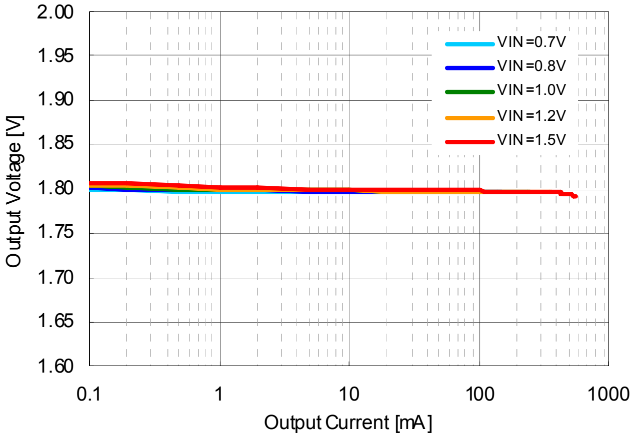
To release the latch protection circuit, toggled input for CE pin is necessary.

Lx current limit(I_{LXPEAK}) and the protection delay time (tprot) are influenced by the self-heating, heat radiation environment at mounting on board. If short circuit may happen, input voltage (V_{IN}) drops largely or becomes unstable, the protection operation and the delay time will be influenced.

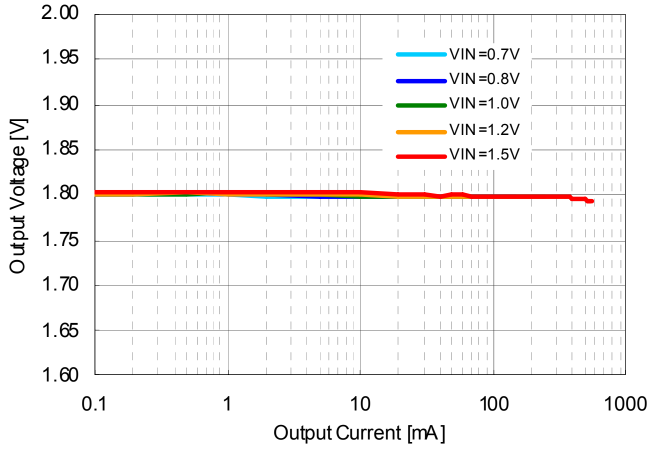
TYPICAL CHARACTERISTICS

1) Output voltage vs. output current (Ta=25°C)

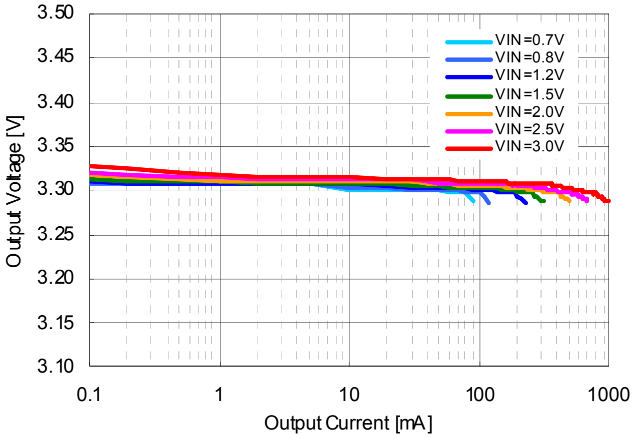
RP401K001x
RP401x181x
V_{OUT}=1.8V
MODE=L



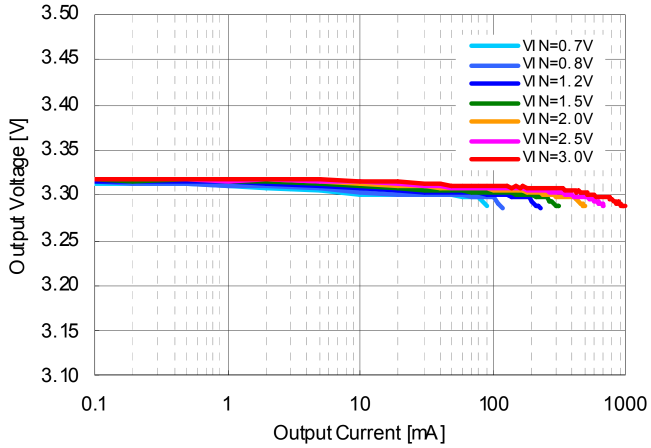
RP401K001x
RP401x181x
V_{OUT}=1.8V
MODE=H



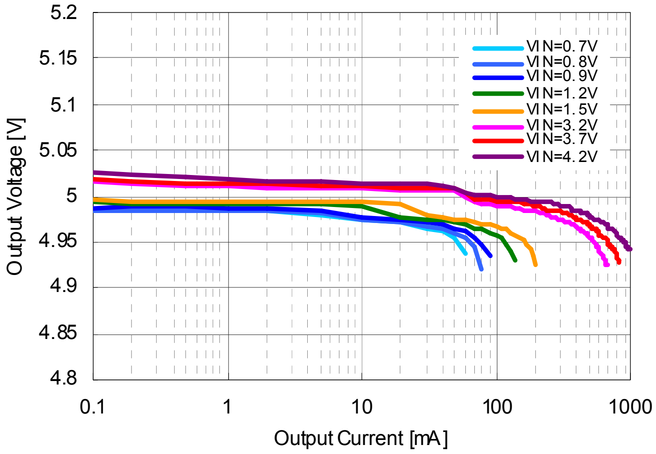
RP401K001x
RP401x331x
V_{OUT}=3.3V
MODE=L



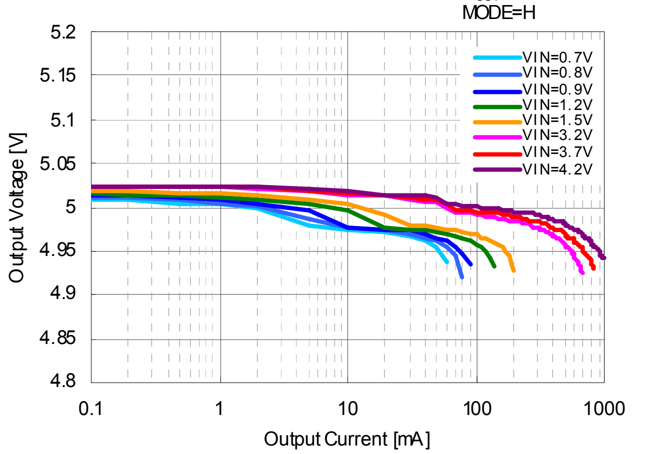
RP401K001x
RP401x331x
V_{OUT}=3.3V
MODE=H

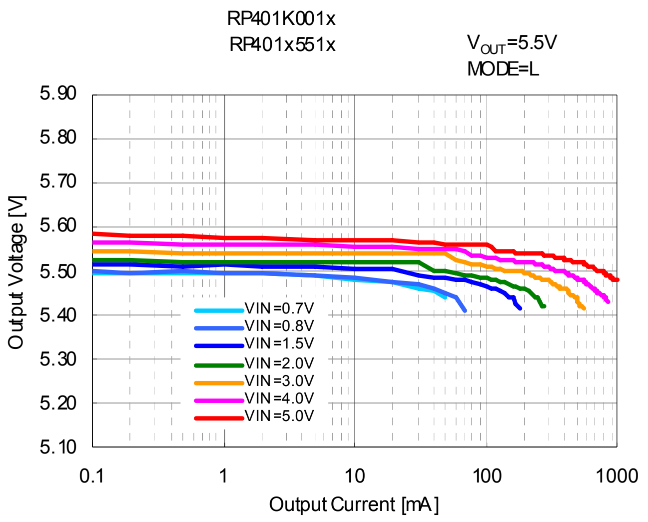


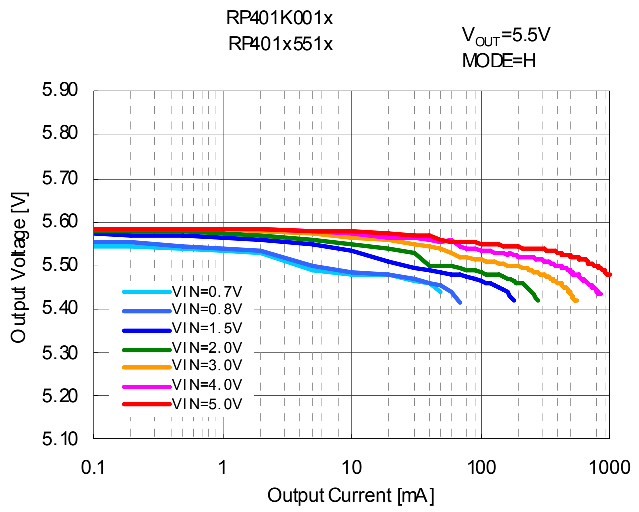
RP401K001x
RP401x501x
V_{OUT}=5.0V
MODE=L



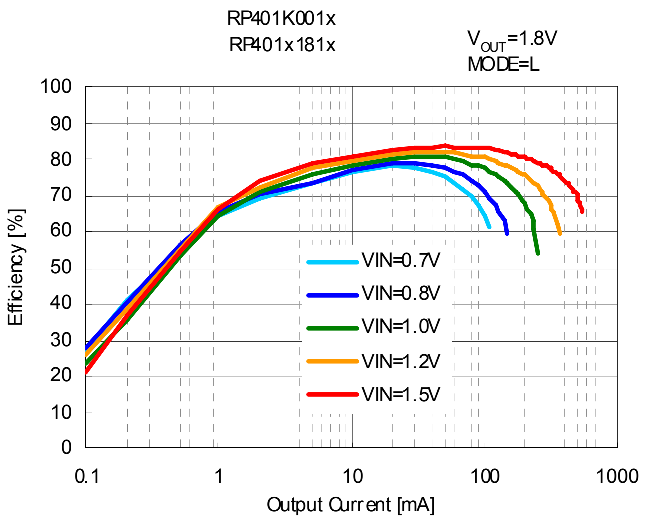
RP401K001x
RP401x501x
V_{OUT}=5.0V
MODE=H

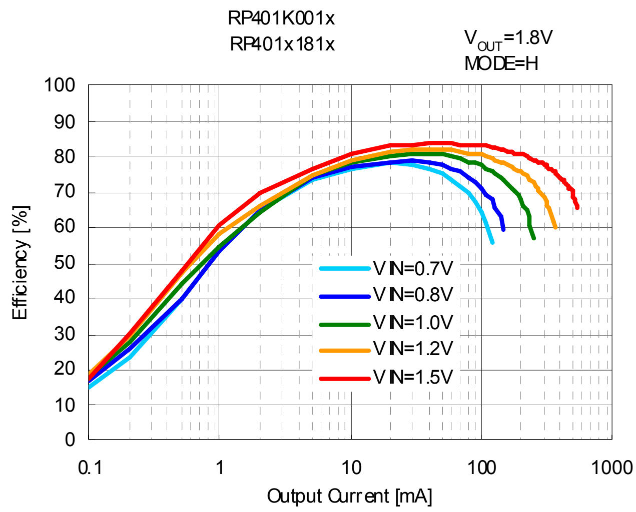


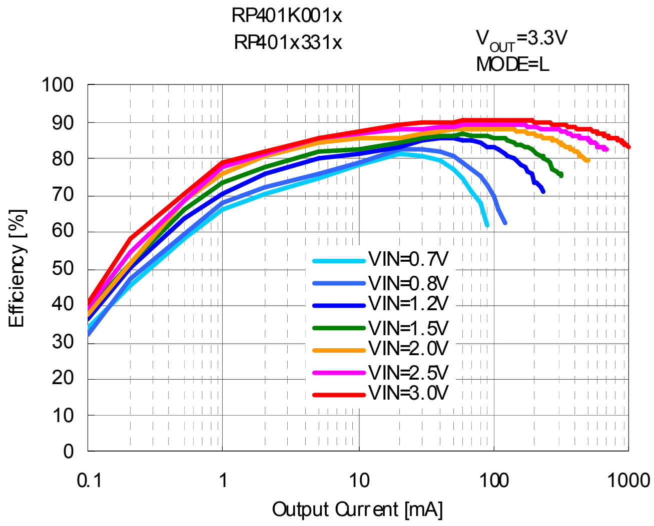


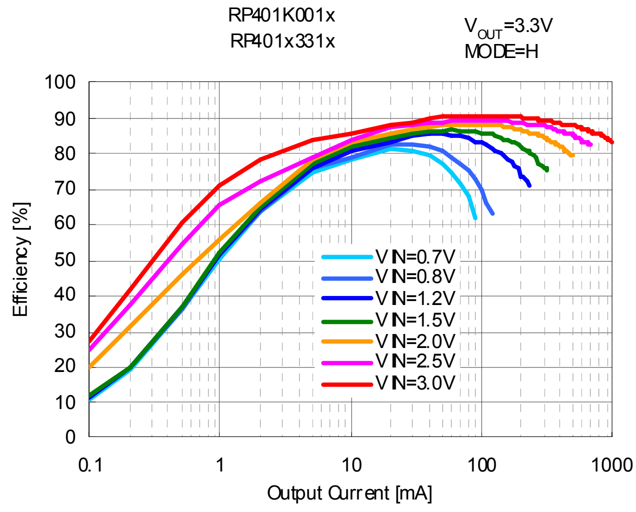


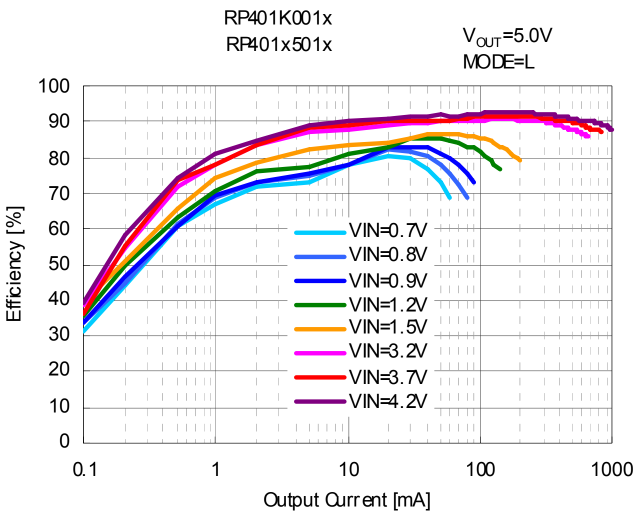
2) Efficiency vs. Output current (Ta=25°C)

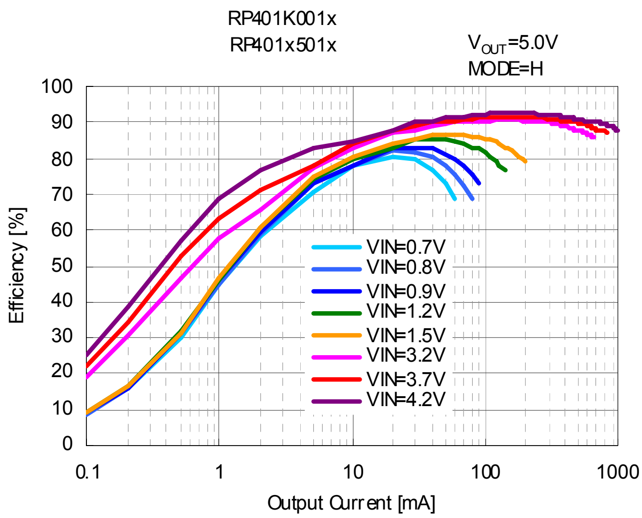


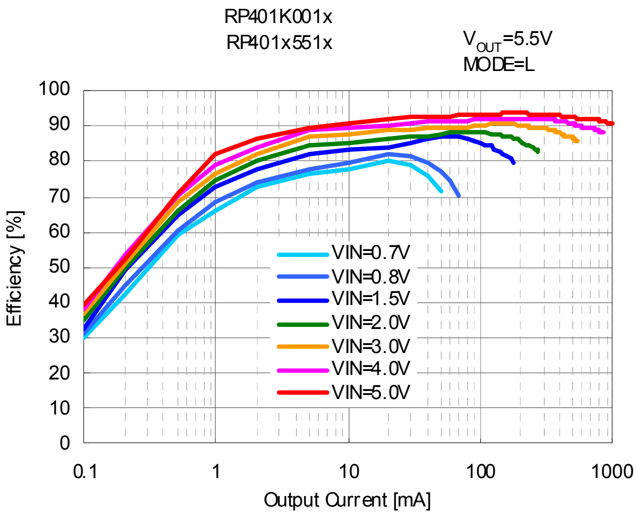


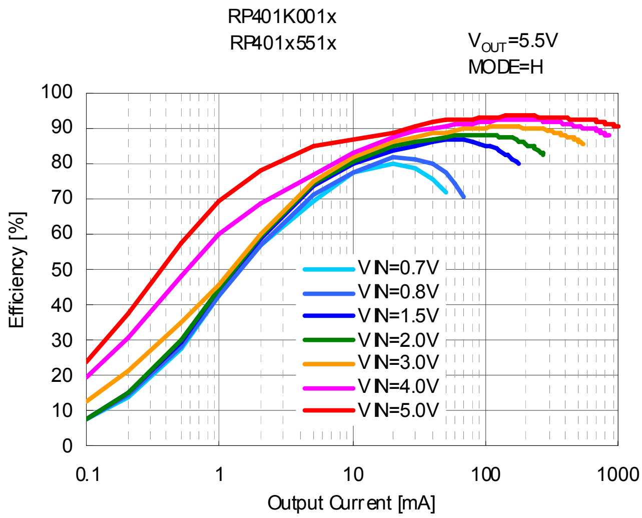




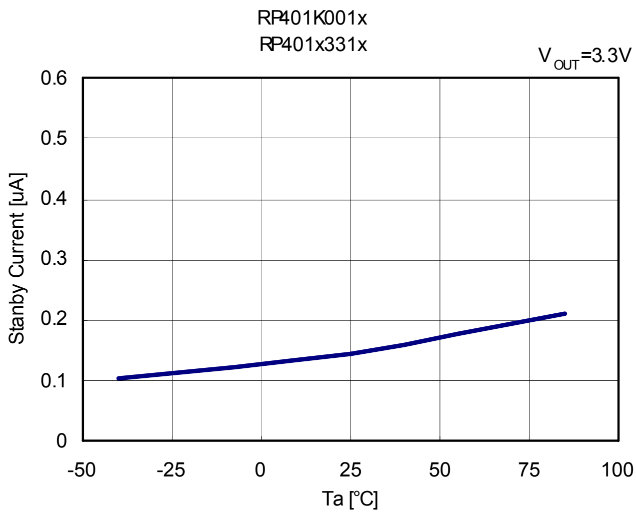




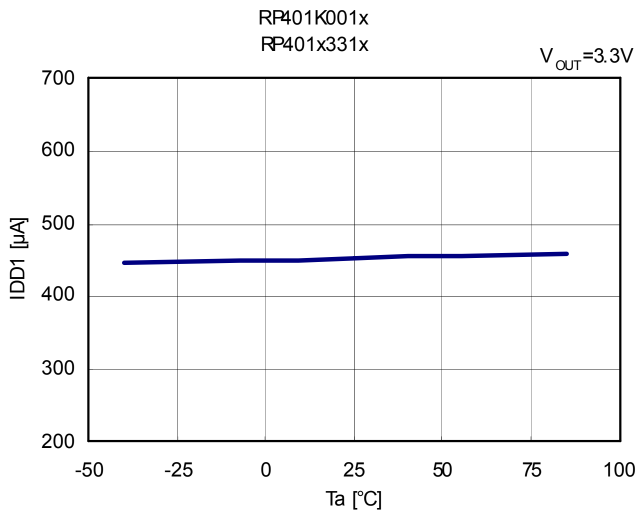




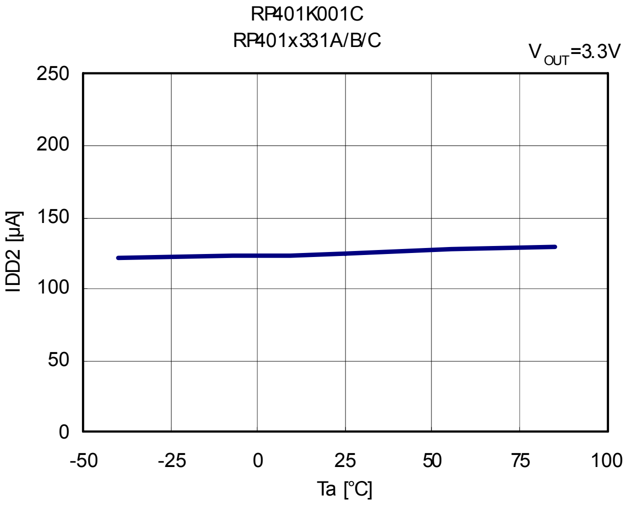
3) Standby Current vs. Temperature

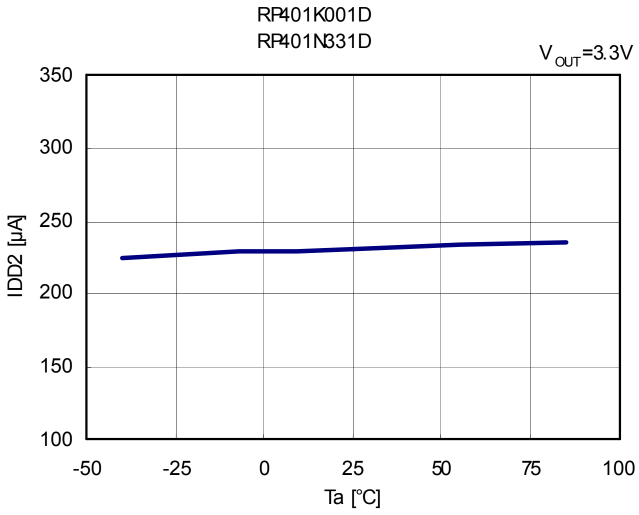


4) Supply Current1 vs. Temperature

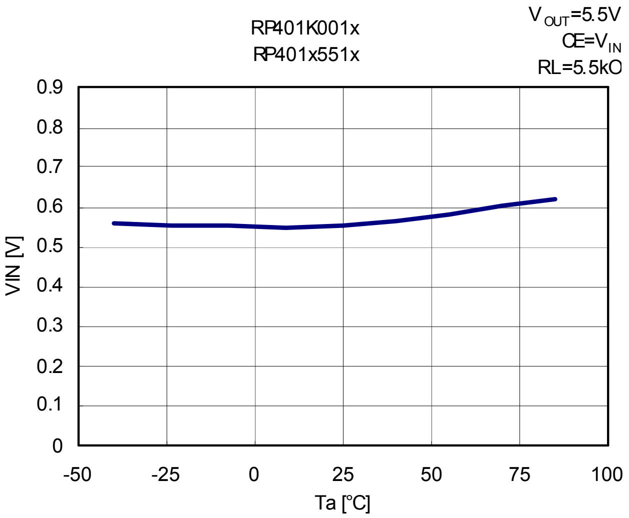


5) Supply Current 2 vs. Temperature

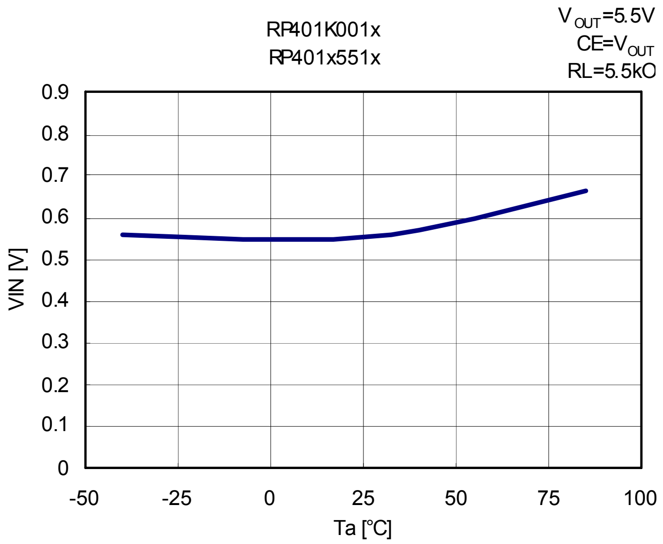




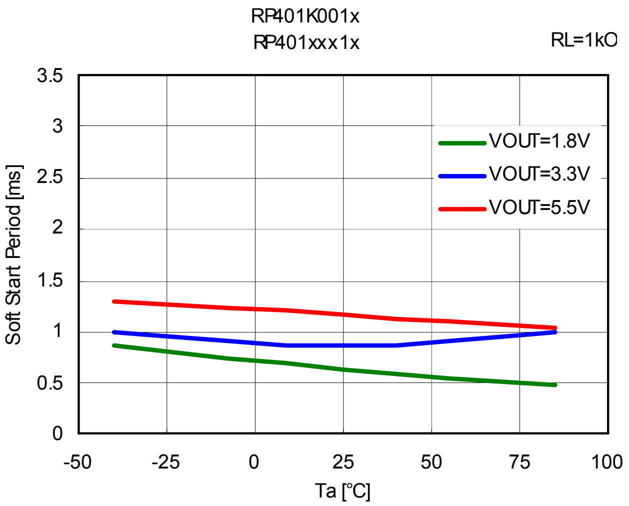
6) Start-up voltage 1 vs. Temperature



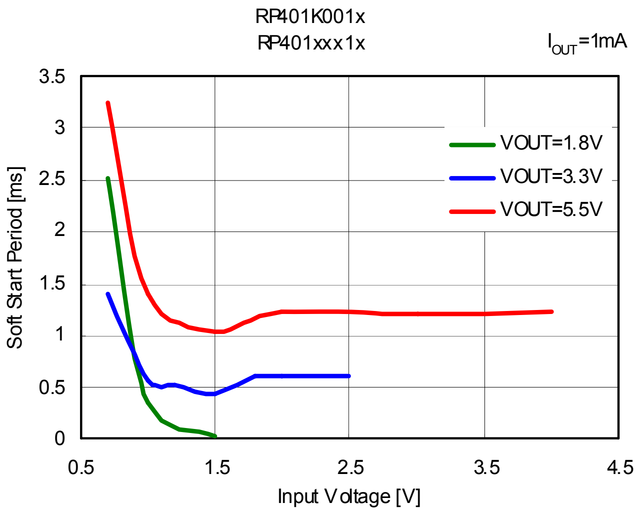
7) Start-up Voltage 2 vs. Temperature



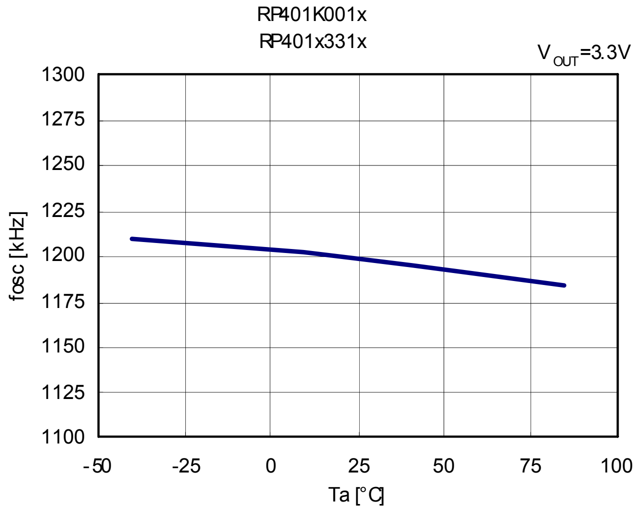
8) Soft start time vs. Temperature



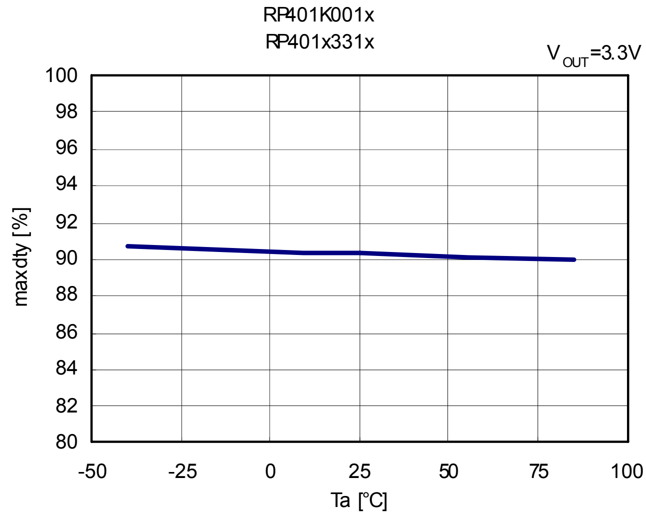
9) Soft start time vs. Input voltage (Ta=25°C)



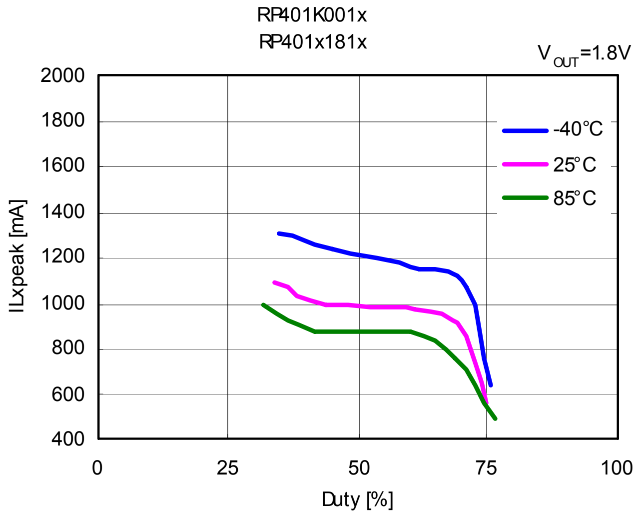
10) Frequency vs. Temperature

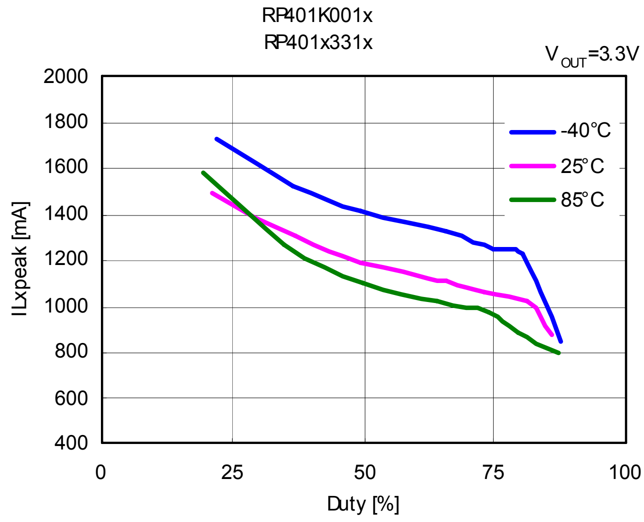


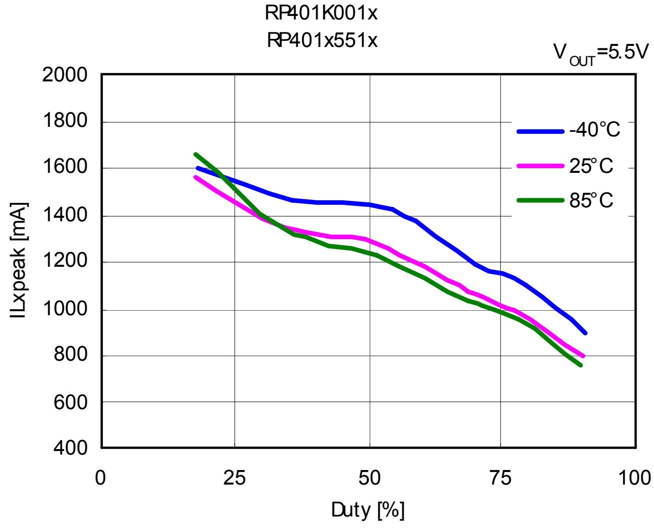
11) Maximum duty cycle vs. Temperature



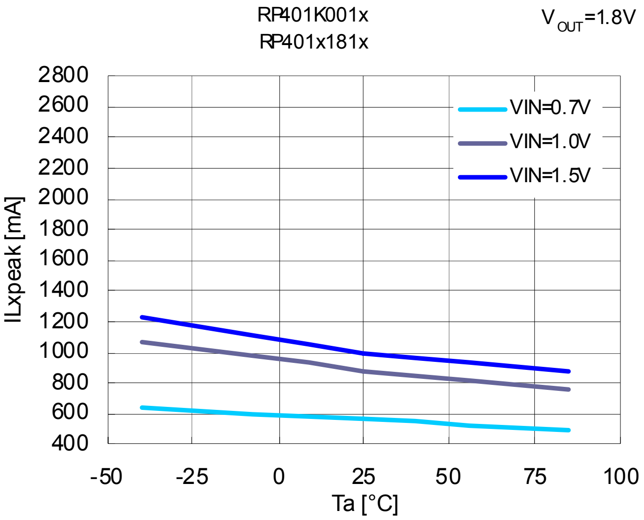
12) Lx current limit vs. duty cycle

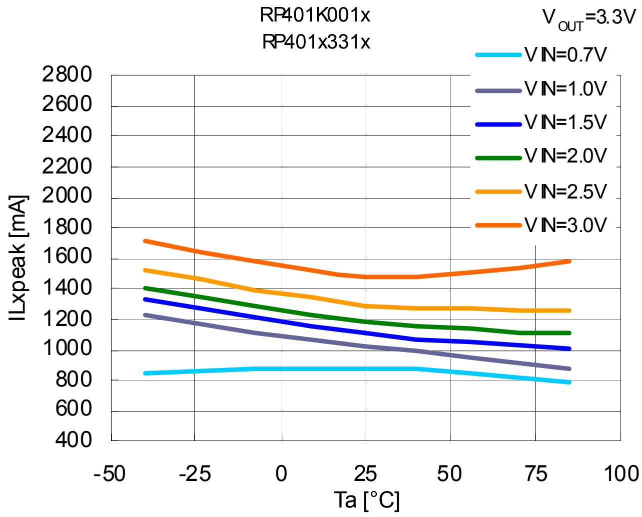


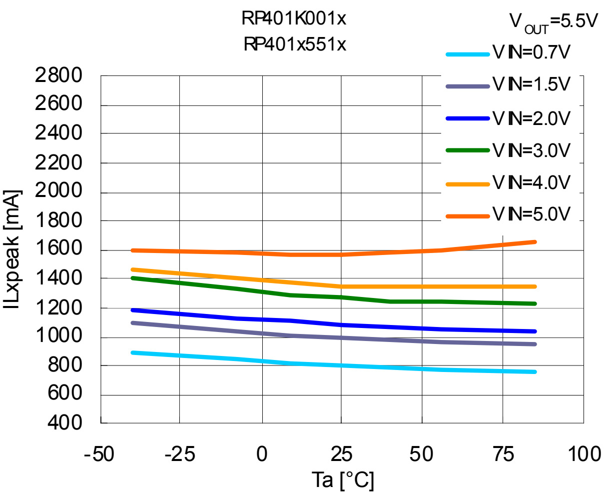




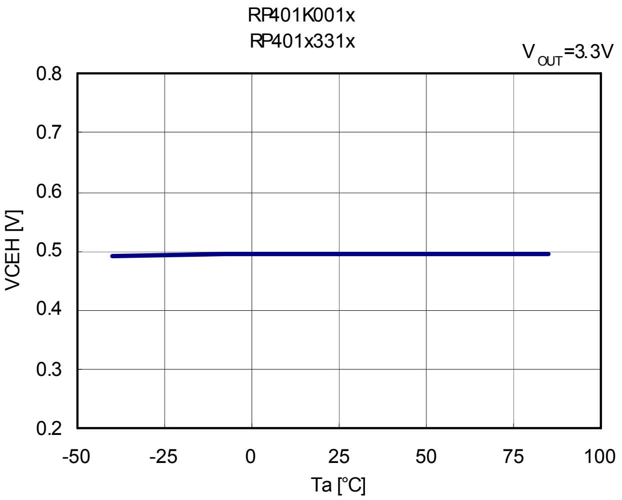
13) Lx Current limit vs. Temperature



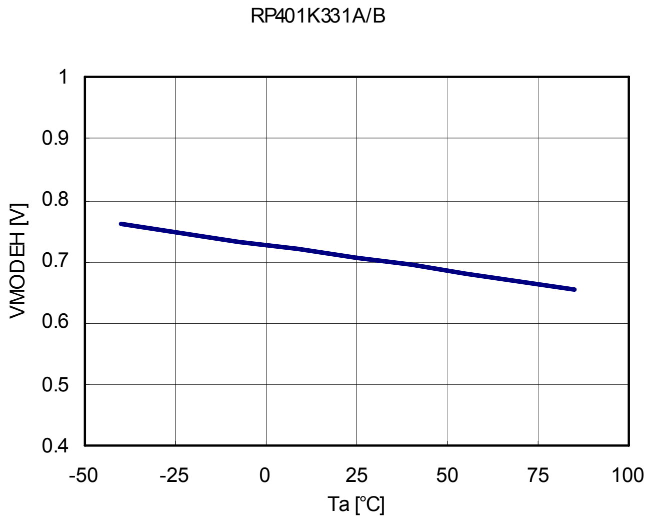




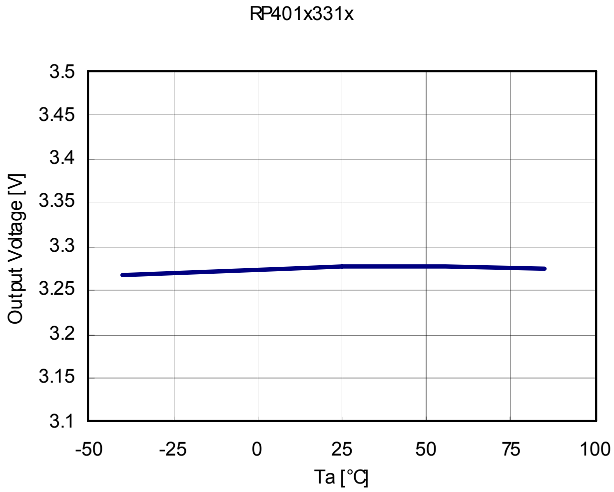
14) CE input voltage "H" vs. Temperature



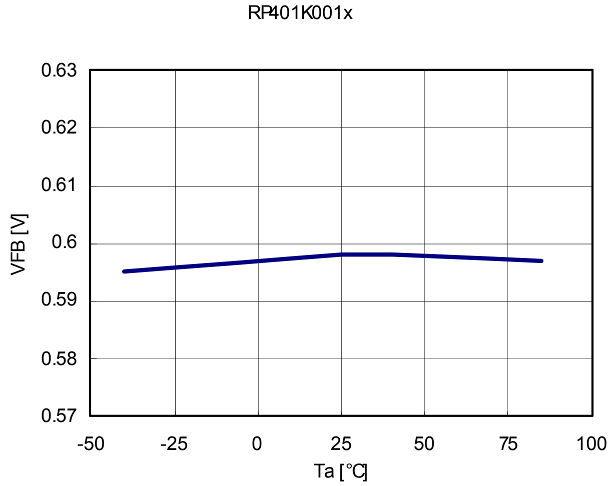
15) MODE input voltage "H" vs. Temperature



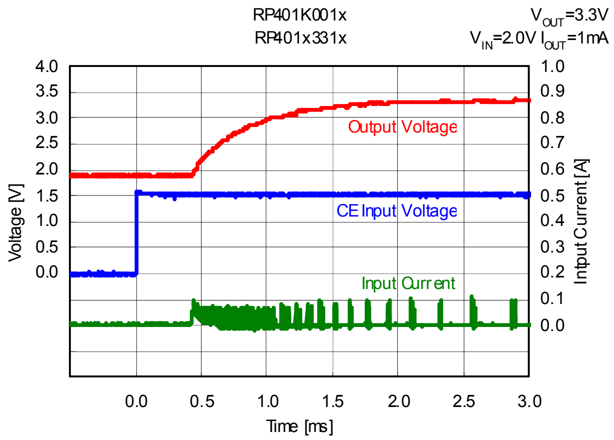
16) Output voltage vs. Temperature



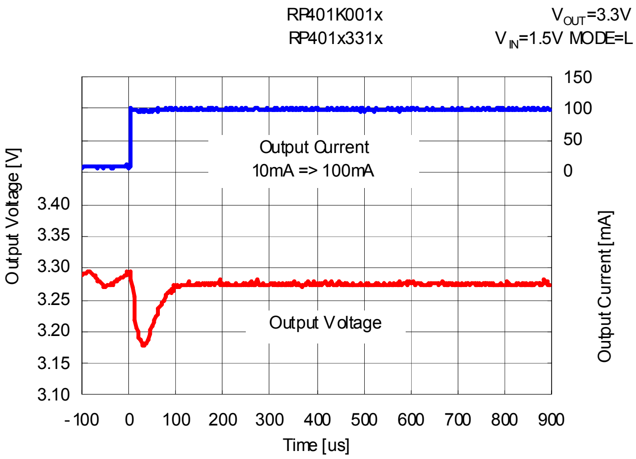
17) Feedback voltage vs. Temperature

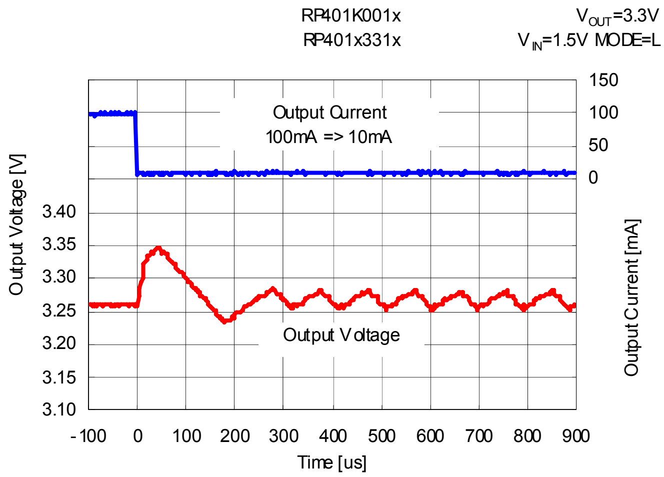


18) Start-up waveform (Ta=25°C)

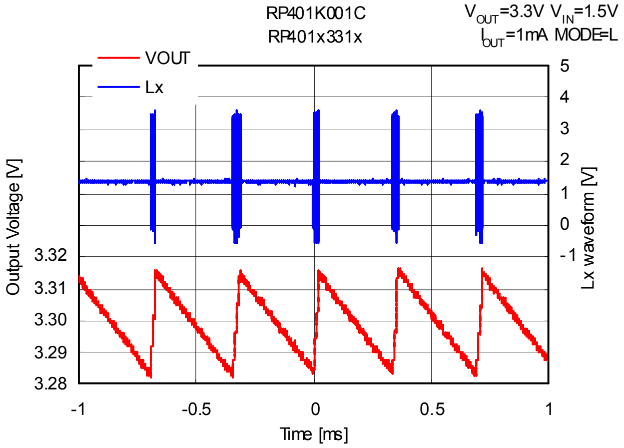


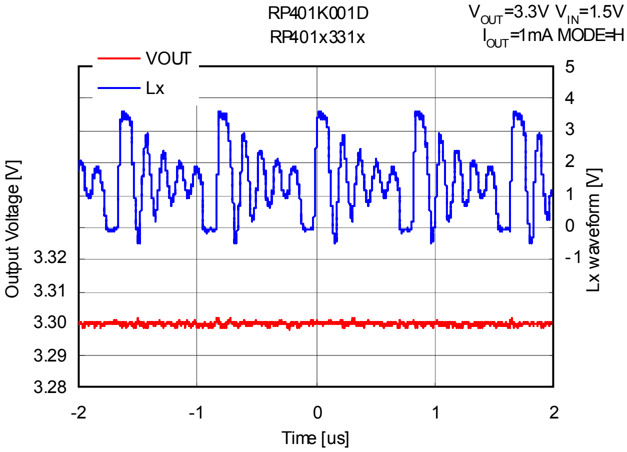
19) Load transient response (Ta=25°C)

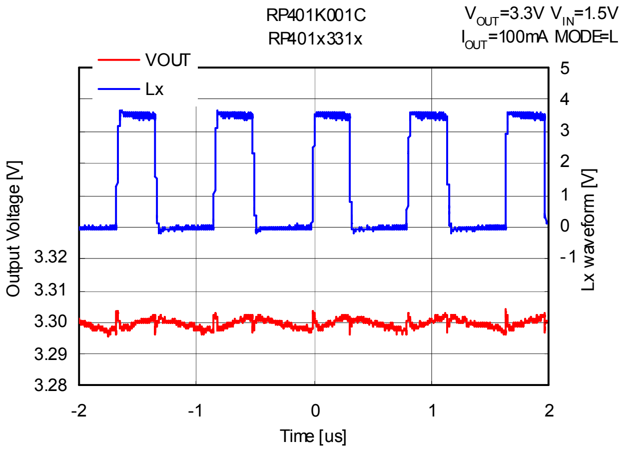


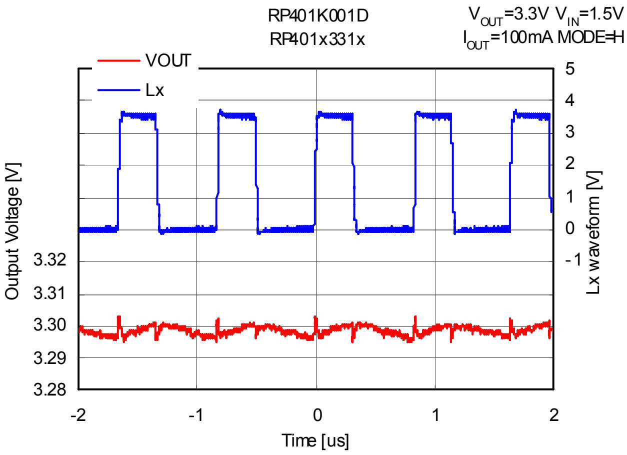


20) Output voltage waveform (Ta=25°C)

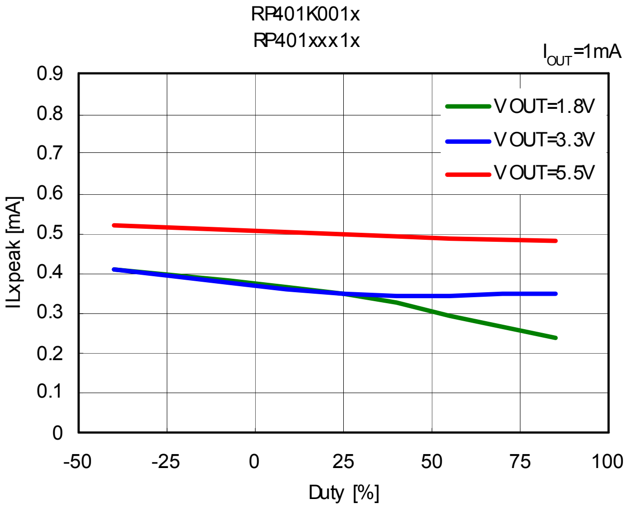






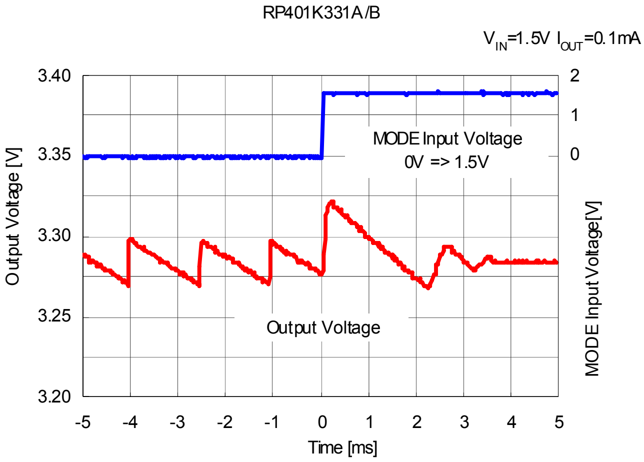


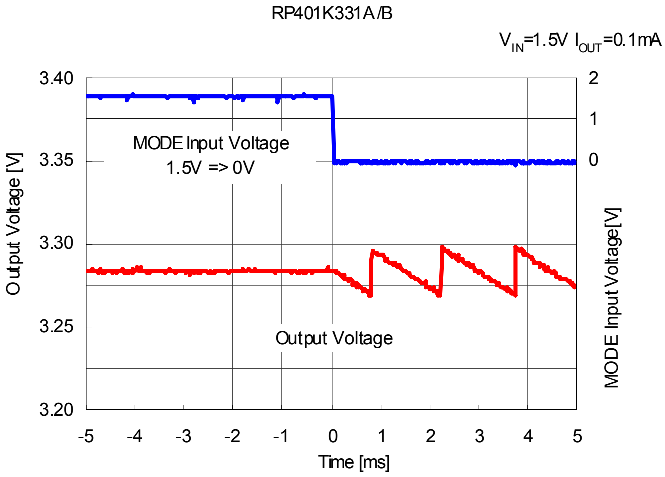
21) Hold-on voltage vs. Temperature



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22) Mode alternative waveform (Ta=25°C)





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